

BeppoSAX/PDS OBSERVATION OF VELA X-1

M. ORLANDINI, D. DAL FIUME, L. NICASTRO,
E. PALAZZI and F. FRONTERA‡

Istituto TeSRE/CNR Bologna

‡ also Dipartimento di Fisica, Università di Ferrara

Abstract

Vela X-1 has been observed by the Italian/Dutch X-ray satellite BeppoSAX during its Science Verification Phase. During the ~ 50 ksec observation (orbital phases 0.27–0.34) two different intensity state are present, situation very common in this source. We report results from the pulse phase averaged and pulse phase resolved spectroscopy from the high-energy instrument PDS aboard BeppoSAX.

1 Introduction

The X-ray binary system Vela X-1 is composed by a neutron star and the B0.5 supergiant HD77851 (Hutchings 1974). The orbit is almost circular, with an orbital period of 8.96 days. The neutron star pulses at about 283 seconds (McClintock et al. 1976), and is occulted by the companion for 1.7 days (Avni 1976). The contemporary presence of pulsations and X-ray eclipses has allowed the determination of the geometry of the system: the neutron star is heavily embedded in the strong stellar wind and both accretion and photoionization wakes are formed during the orbital motion of the neutron star (Kaper et al. 1997).

Vela X-1 shows large temporal variability on time scales from minutes to hours. They have been ascribed to fluctuations in the accretion rate and to inhomogeneities in the stellar wind (Haberl & White 1990). The pulse period itself has changed during the more than 20 years of observations: the variations follows a wavy behaviour, due to fluctuations in the transfer of angular momentum from the wind to the neutron star. The observed flip-flop behaviour of the Vela X-1 spin history has been explained as due to the formation of a temporary accretion disk, that acts as reservoir of angular momentum (Börner et al. 1987). The problem with this interpretation is the very high magnetic field strength necessary for the disk formation.

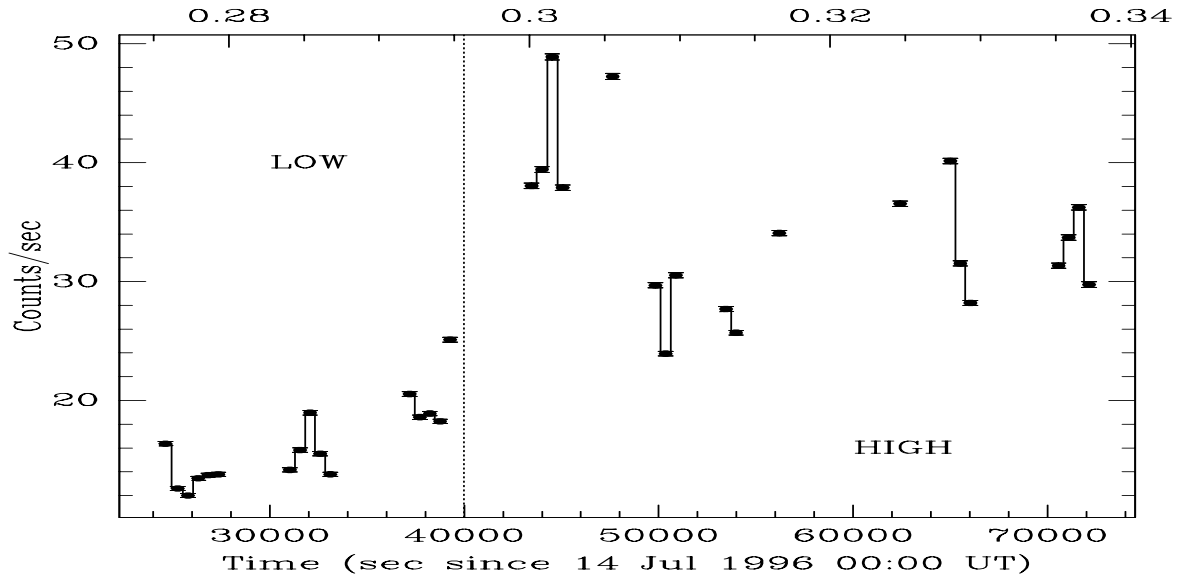


Figure 1: Vela X-1 500 sec background subtracted light curve for 15–300 keV SAX/PDS data. Gaps are due to South Atlantic Anomaly passages, where the instruments are switched off, and occultations by the Earth.

The X-ray spectrum of Vela X-1 has been described by the usual (for X-ray pulsars) power law modified by an exponential cutoff at high energies (White et al. 1983). Due to the absorption of the wind, the pulse-averaged spectrum is very variable along the orbit (Choi et al. 1996): this has been used as tracer of the circumstellar matter. The spectrum also shows an iron emission line (Becker et al. 1978) and line features at ~ 27 and ~ 54 keV that have been interpreted as cyclotron absorption lines (Makishima & Mihara 1992; Kretschmar et al. 1996).

2 Observation

The BeppoSAX satellite is a joint program of the Italian Space Agency (ASI) and the Netherlands Agency for Aerospace Programs (NIVR). The payload includes Narrow Field Instruments (NFI) and Wide Field Cameras (WFC). The NFIs are four Concentrators Spectrometers (C/S) with 3 units (MECS) operating in the 1–10 keV energy band (Boella et al. 1997) and 1 unit (LECS) operating in 0.1–10 keV (Parmar et al. 1997), a High Pressure Gas Scintillation Proportional Counter (HPGSPC) operating in the 3–120 keV energy band (Manzo et al. 1997) and a Phoswich Detection System (PDS) with four detection units operating in the 15–300 keV energy band (Frontera et al. 1997). Orthogonally with respect to the NFIs there are two WFCs (field of view of $20^\circ \times 20^\circ$ FWHM) which operate in the 2–30 keV energy band with imaging capabilities (angular resolution of 5 arcmin) (Jager et al. 1997).

During the Science Verification Phase (SVP) a series of known X-ray sources have been observed in order to check the capabilities and performances of the instruments aboard BeppoSAX. Vela X-1 is one of these sources and it has been observed by three of the four NFIs (LECS was not operative during this pointing).

In Fig. 1 we show the 15–300 keV background subtracted light curve of Vela X-1 has observed by PDS. The operative mode during the observation was DIR001, corresponding to the maximum time and energy resolution (15 μ sec and 1024 energy channels, respectively).

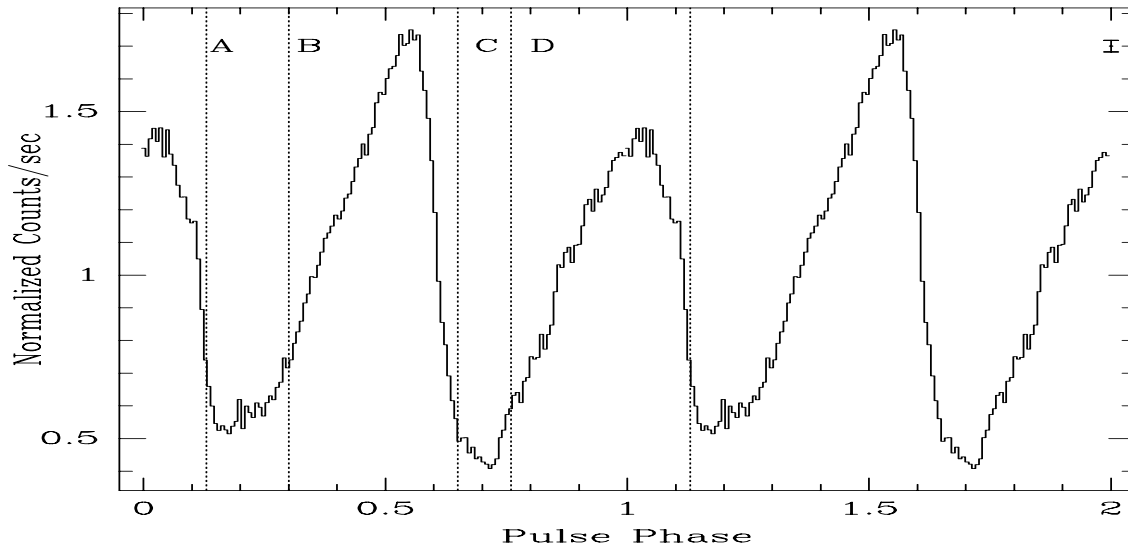


Figure 2: 15–300 keV Vela X–1 normalized pulse profile, together with pulse phase intervals chosen for the pulse phase spectroscopy.

The upper scale represents the orbital phase referred to the ephemeris given by Deeter et al. (1987). The first part of the observation (marked LOW in the figure) corresponds to one of the common intensity dips showed by Vela X–1. Its origin is due to the clumpy circumstellar material that intercepts the emission coming from the pulsar (Sato et al. 1986).

The background evaluation has been performed using the rocking collimator capability of PDS, that allows the contemporary monitoring of the source and the background. The dwell time for this observation was 50 sec, and a Fourier analysis of the background time series did not show the presence of spurious frequencies due to the rocking.

The data analysis has been performed with the XAS package, version 2.0.1, developed by Lucio Chiappetti.

3 Data Analysis

In Fig. 2 we present the 15–300 keV pulse profile of Vela X–1, showing the characteristic double peak structure typical in this energy range (Orlandini 1993). We performed pulse phase spectroscopy on the Vela X–1 PDS data by choosing four pulse phase intervals, as described in the same figure. The 20–200 keV data has been fit with a power law plus exponential cutoff, with the addition of two cyclotron absorption lines (Mihara et al. 1990) for the pulse peak spectra. The results are summarized in Table 1.

The 20–200 keV flux is 5.3×10^{-9} erg cm $^{-2}$ s $^{-1}$, corresponding to an average X–ray luminosity of 2.3×10^{36} erg/sec.

As is evident from the Table 1, the inclusion of cyclotron absorption improves the fits for spectra taken in the pulses, while it is not necessary in the valley spectra. Actually, this is only due to poor statistics, because a ratio between spectra taken in the pulses and in the valleys is nearly constant up to 40 keV. The cyclotron resonance energies in the two pulses are consistent with each other, but in phase D (the secondary peak) only the second harmonic is required. Note also a hardening of the spectrum in the main peak.

We also performed a ratio between the spectra and the featureless spectrum from

Pulse Phase	Avg	A	B	C	D
Fit Param					
α	2.19 ± 0.02	2.44 ± 0.05	2.23 ± 0.02	2.42 ± 0.06	2.25 ± 0.02
I_{70}^*	3.2 ± 0.2	2.1 ± 0.4	4.5 ± 0.4	2.5 ± 0.6	4.4 ± 0.4
E_c (keV)	33.3 ± 0.1	32.8 ± 0.5	35.6 ± 0.2	33.8 ± 0.6	32.7 ± 0.2
E_f (keV)	11.9 ± 0.1	12.8 ± 0.5	12.4 ± 0.2	13.4 ± 0.7	13.0 ± 0.2
χ_{dof}^2	4.81	1.21	4.23	1.07	4.71
α	1.85 ± 0.09		1.45 ± 0.15		1.73 ± 0.14
I_{70}^*	7 ± 2		7 ± 3		15 ± 8
E_c (keV)	30.7 ± 0.5		30.6 ± 0.7		29.4 ± 0.4
E_f (keV)	14.3 ± 0.8		12 ± 1		19 ± 2
E_{cyc} (keV)	28.1 ± 0.2		28.3 ± 0.3		28.9 ± 0.4
$\tau_1 ; W_1$ (keV)	$0.19 \pm 0.06 ; 0$		$0.28 \pm 0.07 ; 5 \pm 2$		$0.5 \pm 2 ; 0.2 \pm 1$
$\tau_2 ; W_2$ (keV)	$0.8 \pm 0.1 ; 9 \pm 2$		$1.2 \pm 0.2 ; 5 \pm 2$		$1.2 \pm 0.2 ; 17 \pm 3$
χ_{dof}^2	2.08		0.93		1.46

* Flux at 70 keV in $10^{-5} \text{ ph cm}^{-2} \text{ sec}^{-1}$

Table 1: Results of the fits to the 20–200 keV Vela X–1 phase resolved spectra with a power law plus exponential cutoff (upper panel), and the same continuum plus absorption cyclotron lines (lower panel). τ and W corresponds to the depth and half width of the line, respectively. The energy of the first harmonic is fixed as the double of the fundamental.

the X–ray pulsar Crab, in order to reduce systematic errors. The fit still requires the inclusion of a cyclotron resonance, with energy of the fundamental at $E_{\text{cyc}} = 28.5 \pm 0.2$ keV for the average spectrum.

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